Texas active target (TexAT) detector - part 2: Monte Carlo simulations

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The TexAT (Texas Active Target) detector is a new active-target time projection chamber (TPC) that will reside at the Cyclotron Institute. The detector is designed to be of general use for experiments relevant to nuclear astrophysics and nuclear structure. The details of the design are described in the previous report [1]. Time projection chambers allow for the 3D track reconstruction of the incoming and outgoing particles involved in a reaction. Ionization electrons from interactions of the particle with the gas volume drift at a uniform velocity to the readout plane, which in this present case is a highly segmented MicroMegas board. The point of detection of the electrons on the readout plane determines two coordinates of the tracks, while the drift time yields the third dimension. In addition to the TPC component, the TexAT tracking volume is also surrounded on five sides by CsI-backed Silicon detectors. See [1] for more details on the design of TexAT.

To reduce the total number of channels on the TexAT MicroMegas board, a unique segmentation scheme was conceived, consisting of rectangular pads in the beam region and overlapping strips and chains to the left and right of the central region. To verify that the chosen pad segmentation would allow for the required vertex and angular resolution, detailed Monte Carlo simulations were performed. These simulations utilized the Geant4 [2] and Garfield++ [3] packages for ion and electron transport, respectively. Two reactions were studied as the test case: ^{12}C(p,p)^{12}C and ^{18}Ne(a,p)^{21}Na. In the latter, residual ^{21}Na nuclei in both the ground state and first excited state were populated. In the simulation, the incoming ions were forced to undergo the reaction of interest at a random point within the TPC using realistic reaction kinematics. At each step of an incoming or product track, the total ionization energy was converted to a number of electron and ion pairs, and each electron was drifted under a constant electric field to the MicroMegas board. Time-dependent histograms of the number of detected electrons for each pad of the MicroMegas board were generated and stored for offline processing. Additionally, the energy collected in each detector of the Silicon array was also recorded per event. Fig. 1 shows an example event visualized in Geant4.

Custom track reconstruction routines have been developed for the TexAT detector. For particles traversing the left and right regions, X-Y coordinates are determined by matching strips to chains (or vice versa) using the average recorded drift time. In the central region, the X-Y coordinates of a track are determined solely from the position of the rectangular pad width the highest electron count per row. Such a procedure yields two tracks: one for the light product and one combined track for the incoming ion and heavy recoil. By finding the point of closest approach of the fitted light product and the heavy ion tracks, the heavy ion track in the central region can be split into separate incoming and recoil tracks. Finally, the three tracks are re-fit simultaneously to find the vertex of the interaction and the relative angles of the reaction

products. Fig. 2 shows an example of the track reconstruction. The blue points are the simulated interaction points, while the yellow, purple and green points are reconstructed from the

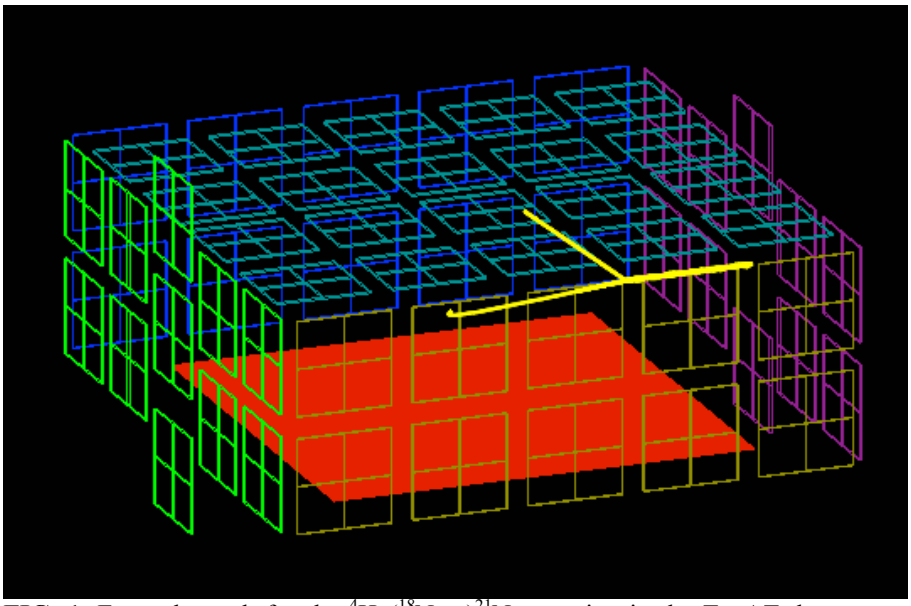

FIG. 1. Example track for the ^{4}He(^{18}Ne,p)^{21}Na reaction in the TexAT detector as visualized in Geant4. The light recoil (proton) hits the Si detector on the top plate and the heavy recoil (^{21}Na) stops in the gas volume.

information recorded from the simulation for the MicroMegas board. The black lines are the fitted tracks, and the teal point indicates the fitted reaction vertex. For the reactions of interest, the vertex reconstruction error was found to be approximately 1.5 mm on average, with a distribution that peaked below 1 mm. The angular resolution determined from the simulation was approximately 3 degrees at FWHM. If the Q-value of the reaction is unknown, the center of mass

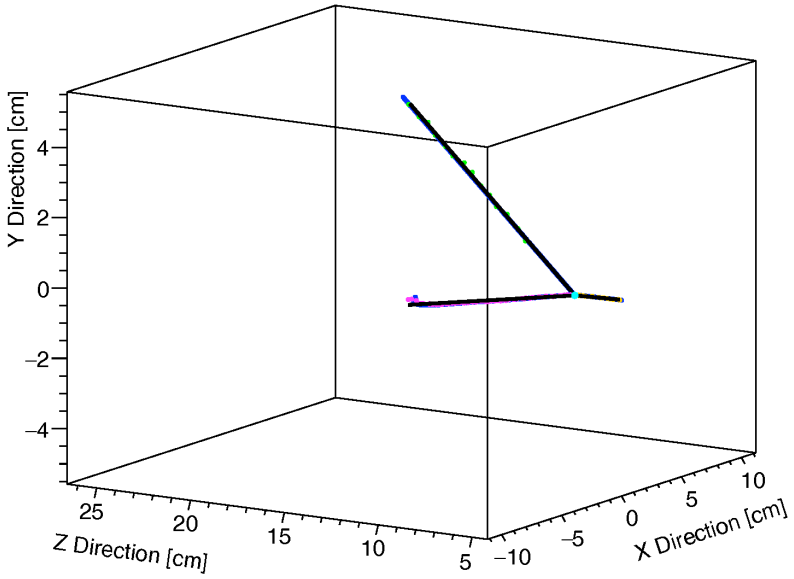

FIG. 2. Same track as in Fig. 1, but reconstructed from drifted electrons detected by the MicroMegas pads.

energy of the interaction can only be reconstructed from the vertex position and the average energy loss in the gas, and is limited by energy straggling effects. For the incoming ^{18}Ne ions, this yielded a center of mass energy resolution of 190 keV at FWHM. Using the interaction energy as provided by the vertex, in addition to the angle and energy (measured in Si detectors) of the light product, the Q-value can be reconstructed. In the case of the ^{18}Ne(a,p)^{21}Na reaction, transitions to the ground and first excited states of ^{21}Na (separated by only 330 keV) could be well resolved (see Fig. 3). Once the reaction mechanism is identified (e.g. elastic or inelastic scattering), the c.m. energy resolution can be improved by recalculating using the Q-value, the detected energy in the Si detector, and emitted light product angle. In the present study, the center of

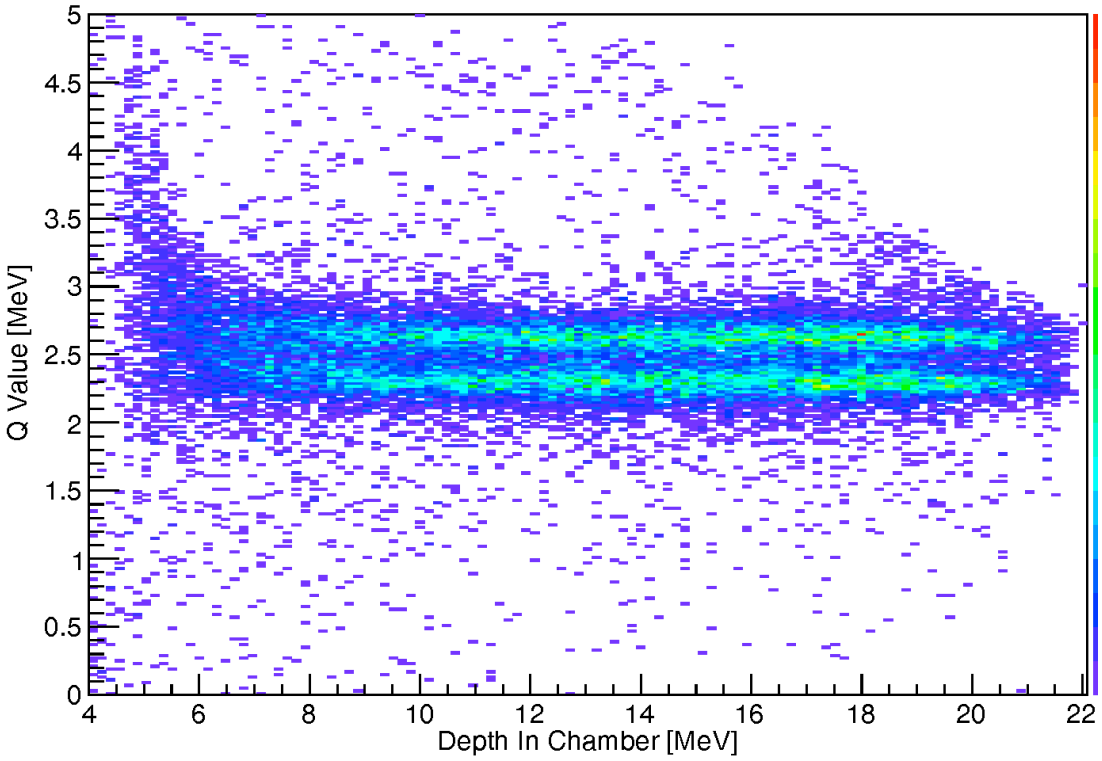

FIG. 3. Reconstructed Q-value vs. chamber depth for the simulated ^{18}Ne(α,p)^{21}Na reaction.

mass energy resolution for these events was found to be 40 keV at FWHM (see Fig. 4). Additionally, these energy and angle resolutions were found to be mostly insensitive to the depth within the scattering chamber and therefore interaction energy and scattering angle.

In summary, detailed Monte Carlo simulations of the TexAT detector have been performed to test the design characteristics against relevant example reactions. Algorithms have been developed for the reconstruction of the tracks within the TPC volume and the resulting

reaction kinematics. With the current segmentation, the observables can be reconstructed with enough precision to separate two closely spaced excited states for a relevant inelastic two-body reaction. It was shown that track reconstruction allows for excellent energy and angular resolution over wide range of excitation energies and scattering angles for various reaction types.

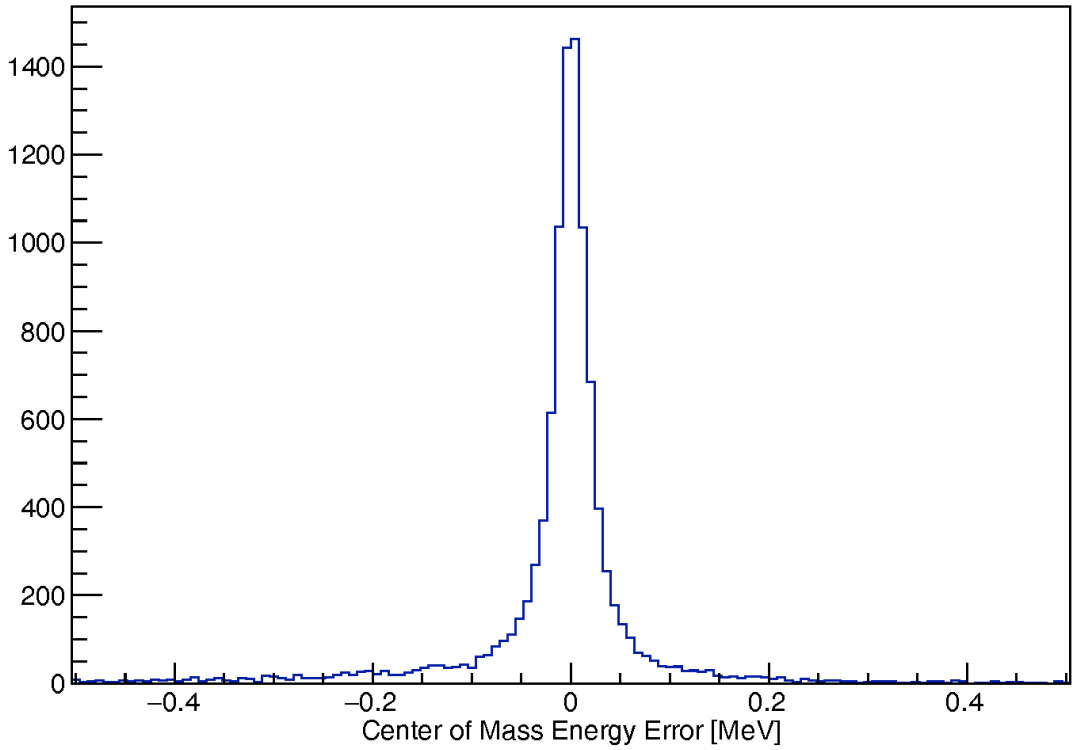

FIG. 4. Center of mass energy resolution for the simulated $^{12}C(p,p)^{12}C$ reaction.

[1] E. Koshchiy, G.V. Rogachev, E. Uberseder and E. Pollacco, *Progress in Research*, Cyclotron Institute, Texas A&M University (2014-2015), p.IV-42.

[2] S. Agostinelli *et al.*, Nucl. Instrum. Methods Phys. Res. A**506**, 250 (2003).

[3] http://garfieldpp.web.cern.ch/